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ABSTRACT

A lightweight accelerometer has been used to produce a waveform related to the glottal acoustic output when attached to the throat of a speaker, and to provide an indication of acoustic coupling to the nasal cavities when attached to the external surface of the nose. Examples of signals produced by the accelerometer are shown, and possible application in speech training are discussed. (Author)

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THE USE OF A MINIATURE ACCELEROMETER FOR DETECTING GLOTTAL WAVEFORMS AND NASALITY

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The Use of a Miniature Accelerometer for Detecting Glottal Waveforms and Nasality[1]

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Abstract

A lightweight accelerometer has been used to produce a waveform related to the glottal acoustic output when attached to the throat of a speaker, and to provide an indication of acoustic coupling to the nasal cavities when attached to the external surface of the nose. Examples of signals produced by the accelerometer are shown, and possible applications in speech training are discussed.

This note describes the use of a lightweight transducer to produce a waveform representative of the glottal acoustic output when attached to the throat of a speaker, and to provide a measure of the degree of acoustic coupling to the nasal cavities through the velopharyngeal opening when attached to the external surface of the nose.

The transducer is a miniature accelerometer (Bolt Beranek and Newman Model 501). It is housed in a cylindrical casing of height 0.330 inch and diameter 0.312 inch, and its total weight is 1.8 grams. The casing contains both a piezoelectric transducer and a preamplifier circuit. Figure 1 shows the accelerometer attached to the throat and to the nose, and illustrates the small size of the device. Nominal sensitivity of the unit is 8 mv/g. The frequency response is flat to within 5% over the range 8 to 20,000 Hz. The accelerometer can withstand shocks of 10,000 g's without damage. The preamplifier requires 1 ma. of current at 9 v.d.c. These features of light weight, good sensitivity, wide bandwidth, ruggedness and low power consumption make the device suitable in applications where speech-related signals need to be extracted and displayed, such as speech-reception aids for the deaf, speech training of the deaf or of cleft-palate patients, training of pronunciation of a second language, or even speech pick-up in high-intensity noise environments, since the accelerometer is relatively insensitive to airborne sound.

The accelerometer may be easily attached to the throat or nose of a speaker by means of double-sided adhesive tape. Once in place, the accelerometer is barely noticeable; subjects can wear it for hours without discomfort.

Fig. 1. Showing the accelerometer in position for detection of pitch and nasality.

Glottal Waveform

One application of a throat-attached accelerometer is to obtain a waveform from which glottal periodicity or fundamental frequency can be conveniently extracted. Derivation of fundamental frequency is more complex with the signal derived from a microphone mounted near the mouth, since this signal has a richer harmonic structure and may include interference from background noise. While real-time pitch extraction can be achieved from voice signals alone, a procedure based on throat-derived signals is simpler and more reliable. The waveform from the accelerometer is also potentially useful in basic studies of speech production and, perhaps in diagnosis of abnormalities of the larynx or in the subglottal airways (since an acoustic resonance of the subglottal system can be observed in the waveform, as noted below). Other kinds of throat-attached sensors have been used for the purpose of obtaining a harmonic-free glottal waveform, but in general these have been less convenient and more bulky than the accelerometer described here (Sugimoto & Hiki, 1960; Porter, 1963; Tjernlund, 1964; Fourcin & Abberton, 1971).

Figure 2 shows the simultaneous throat accelerometer and microphone waveforms of a male speaker uttering several vowels. The voice signal was recorded using an Electro-Voice RE 15 microphone at a distance of 12 inches from the speaker. The accelerometer provides a waveform with relatively little harmonic content and fairly uniform amplitude. For these utterances, the accelerometer was mounted in the mid-sagittal plane midway between the thyroid cartilage and the sternal notch. The time lag between the accelerometer waveform and the output of the voice microphone is about 1.5 msec., approximately the time needed for sound to propagate from the glottis to the microphone. The

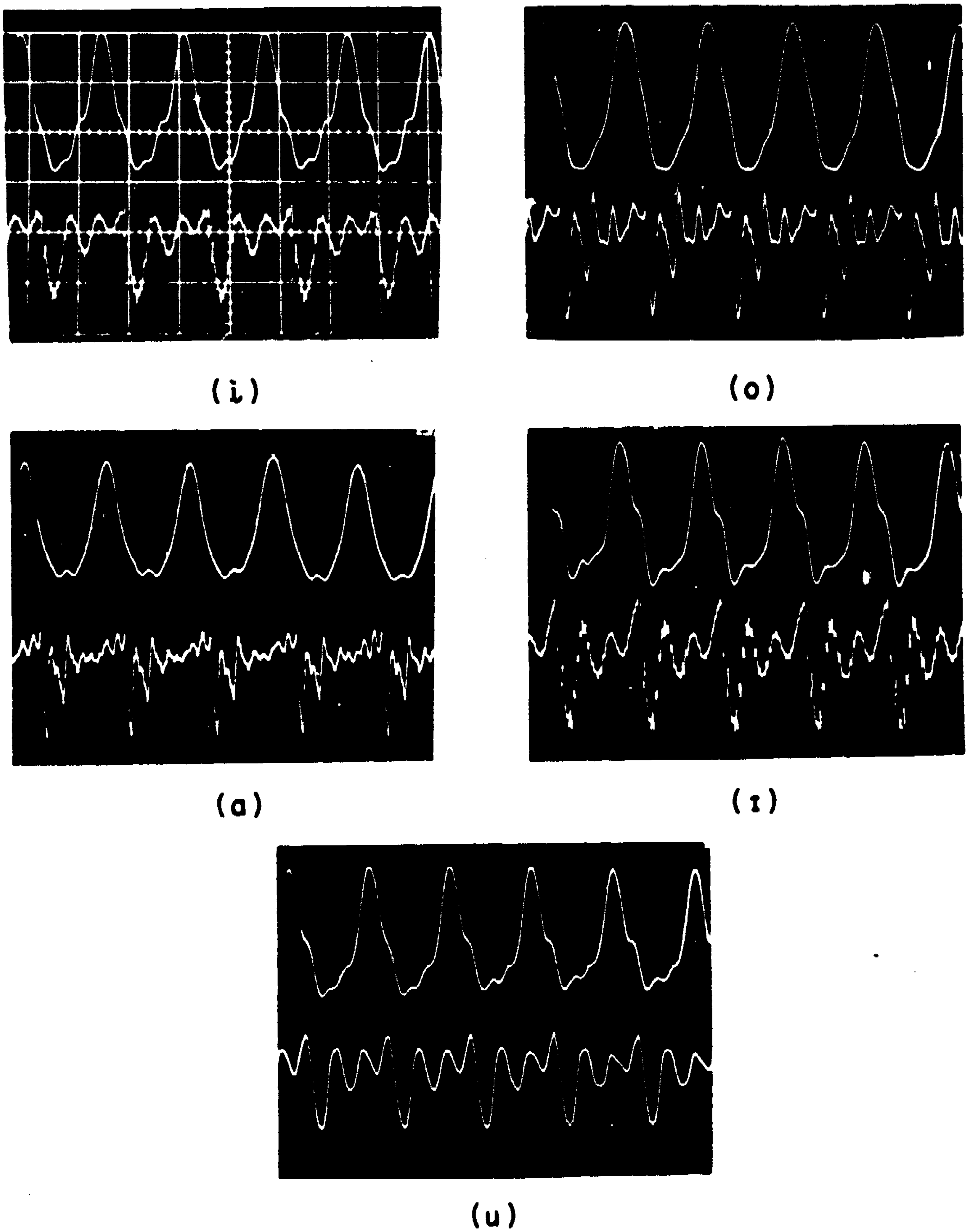

Fig. 2. Accelerometer output (upper trace) and sound-pressure waveform (lower trace) for a male speaker producing various sustained vowels. Fundamental frequency is 118 Hz.

ripple visible on the accelerometer output has a frequency of about 500 Hz, irrespective of vowel; its amplitude depends somewhat on the vowel. Observations of waveforms recorded from other speakers confirm the presence of a similar ripple whose frequency is vowel-independent but speaker-dependent, the frequency of the ripple for females being higher than that for males. This ripple is presumably the result of acoustic excitation of the lowest natural frequency of the subglottal system, which is known to be in the vicinity of 500 Hz (Fant, et al., 1972)[2]. It is apparent from Fig. 2 that the accelerometer gives a peaked waveform that can be used with simple signal processing techniques to provide an indication of glottal periodicity.

Experiments were performed to determine the amplitude of the accelerometer output and the amount of harmonic content as a function of the mounting position on the throat. The results indicate that a point midway between the thyroid cartilage and the sternal notch and in the mid-saggital plane gives waveforms with maximal amplitude and minimal harmonic content. With the accelerometer in this location, there is little variation in waveform from one vowel to another. The exact positioning of the accelerometer in the vicinity of this point is not critical.

The throat-attached accelerometer, together with frequency-measuring and interfacing circuitry, is currently being used in a computer-based system of speech-training aids for deaf children (Nickerson & Stevens, 1973), and in a similar system for the training of pronunciation of a second language (Kalikow & Swets, 1972). The pitch extractor operates reliably over a range of subjects including adult males, adult females, normal-speaking children and deaf children.

Nasality Detection

When, during voiced speech (i.e., during portions of utterances produced with the vocal cords vibrating), the speaker lowers his velum, acoustic energy emanating from the glottis is modified by both the mouth and nasal cavities. The effects of the nasal cavities on the characteristics of the acoustic speech wave as transduced by a microphone are subtle, whereas the signal at the nose provides a more direct indication of a lowered velum. The acoustic energy propagated through the velar opening into the nasal cavities is signaled unequivocally by an increase in the vibration of the skin of the nostril.

To provide an instantantous indication of this correlate of velopharyngeal opening, the output of the accelerometer attached to the nose[3] is filtered, rectified, and smoothed with an averaging time of about 20 msec. With the aid of a computer, this smoothed signal is sampled at 10-msec intervals, log-converted, and displayed on an oscilloscope.

The degree to which a display of this type can indicate differences between nasal and non-nasal speech sounds is illustrated in Fig. 3. This figure shows the display of the nasal accelerometer output for three phrases produced by a normal adult male speaker: one phrase (<u>his father</u>) contains no nasal consonants, another (<u>his mother</u>) contains one nasal, and a third (<u>my money</u>) contains several nasal consonants. Quantitative measurements have shown that the output for nasal sounds is 10-20 dB above that for non-nasal vowels (Stevens, et al., 1974). The difference is greatest for non-nasal, non-high vowels, and is as small as 10 dB only for the non-nasal vowel /i/. The curves clearly show the regions of the speech in which there is a velopharyngeal opening and demonstrate

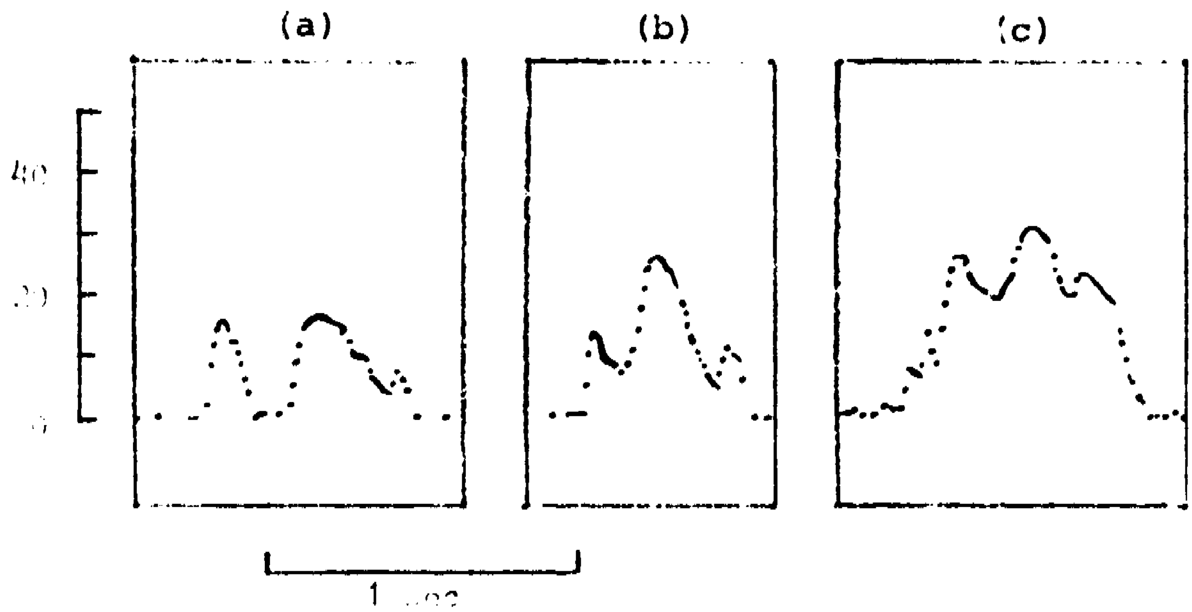

Fig. 3. Computer-derived and -displayed "nasality function" for three phrases produced by a normal male speaker: (a) "his father," (b) "his mother," and (c) "my money." See text.

the well-known fact that the nasalization for a nasal consonant extends into vowels adjacent to the consonant.

A display of the type shown in Fig.3 can be used, therefore, to indicate presence or absence of nasality in speech sounds, where by nasality we mean the presence of a velopharyngeal opening sufficient to cause substantial acoustic coupling between the oropharyngeal and nasal cavities. The question of whether a measure obtained from this display correlates with subjective judgments of nasality[4] is, of course, one that cannot easily be resolved, in view of the long history of difficulties in relating physical measures to nasality judgments. (See, for example, Shelton, et al., 1967; Lubker and Moll, 1965; House and Stevens, 1956; Colton and Cooker, 1968.)

Figure 4 shows the nasality display for a deaf child with severe problems in controlling the velum; for comparison, the display is also shown for a normal speaker producing the same sentence. The sentence for the deaf child is longer than that for the normal speaker. Some vowels are too nasal (the vowels in <u>you</u> and <u>your</u>), and some nasal consonants are replaced by stops (the nasal consonants in dri<u>n</u>k and <u>m</u>ilk).

This type of nasality display has been incorporated in the above-mentioned system of speech-training aids for deaf children. Provision has been made for setting a nasality "threshold" on the display under the control of a teacher, to provide some kind of "target" for the student to aim for. The student attempts to maintain the contour below this threshold during a non-nasal

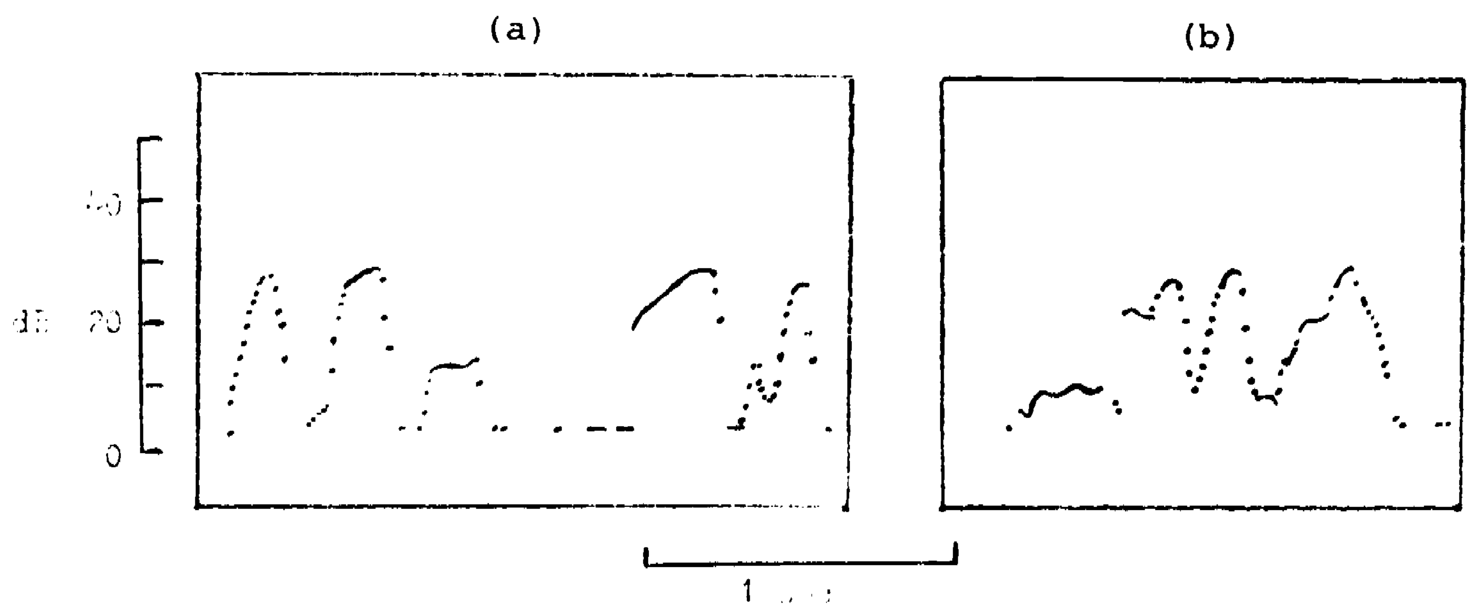

Fig. 4. Nasality display for the sentence, "You can drink your milk," produced by: (a) a deaf child with problems of velar control, and (b) a normal adult male speaker. The five syllables in the sentence are indicated above each version. See text.

utterance or during the non-nasal portion of an utterance. The system also permits the teacher's nasality trace to be stored on one part of the display, to allow visual comparison of the utterances of student and teacher. The display is proving to be successful in indicating to a deaf student when his velopharyngeal port is closed. Training procedures are being devised and experiments are in progress to determine how a display of the type shown in Figs. 3 and 4 can be most effectively used for speech training with deaf children who have inadequate control of the velum but who presumably have an intact neuromuscular system for manipulating the velum.

NOTES

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2. A more detailed interpretation of the characteristics of the waveform of the output of an accelerometer placed on the throat has been given by Henke (1974).

3. A similar transducer arrangement for detecting acoustic coupling to the nasal cavities has been used by Holbrook and Crawford (1970). Various other methods of detecting degree of palatopharyngeal competence include measurement of the flow of air through the nose (Lubker and Moll, 1965; Quigley, et al., 1964) or the acoustic energy radiated from the nostrils (Fletcher, 1970; Shelton, et al, 1967).

4. This question is discussed in more detail elsewhere (Stevens, et al, 1974). That paper also shows data on measures derived from the accelerometer output for groups of normally-hearing adults and children, and for a group of deaf children.

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